2021 IBC Provisions for Performance-Based Design and Prevention of Roof Aggregate Blow-Off

By Jay Crandell, PE; and Chadwick Collins

Figure 1 – Aggregate blow-off initiation due to vortices at building corners for a quartering wind direction.

INTRODUCTION

Low-slope built-up roofing (BUR) systems have featured stone aggregate surfacing for decades. The aggregate serves several purposes; the primary role is to protect the asphalt material from exposure to ultraviolet (UV) radiation, but the material also offers additional benefits such as insulating, thermal mass, and solar reflectance. In fact, aggregate-surfaced roof systems have been exempted from some solar reflectance testing code requirements in recognition of their thermal and solar benefits. In addition to the benefits cited here, the state of Florida passed legislation in 2007 (SB 2836) that recognized the role of gravel-surfaced roofs as nesting bird habitats.

Aggregate used as a roofing surface does raise additional questions about how high winds can affect the material. Because some or most of the aggregate is typically loose-laid, exposure to wind on the rooftop can cause it to move. In extreme events, and depending on the specific details of the roof assembly (adjacent walls, parapets, etc.), aggregate can blow off. When this occurs, the aggregate can cause damage to the building or adjacent buildings.

After Hurricane Katrina struck New Orleans, observed damages from aggregate to glazing were reported, leading various parties to undertake an effort to limit the use of aggregate through changes in the 2006 Edition of the *International Building Code (IBC)*.

ICC Code Proposal S1-03/04, submitted by the Structural Engineers Association of Washington, was approved by the IBC Structural Committee in 2003 and reaffirmed the following year at the ICC Public Comment Hearings. This new code provision banned the use of roofing aggregate on buildings located in the hurricane-prone region, and included limitations on its use on buildings outside of that region. As noted in the following, there were technical deficiencies in the methodology used for the ban and the limitations. In particular, observations made in New Orleans in the windborne debris region were expanded to include broader areas within the hurricane-prone regions of the U.S. and beyond.

Concern with roof aggregate blow-off is not new, and it predates the Katrina observations (Dikkers et al., 1971; Minor, 1977; Savage et al., 1984; Kareem, 1986; McDonald et al., 1990; Smith et al., 1992; FEMA 488, 2004; FEMA 549, 2005). It has continued to be reinforced by field observations, particularly in regard to damage caused to glazing on surrounding buildings and automobiles. Most problems have been associated with:

- Extreme wind events, such as hurricanes,
- Have involved roofs not in compliance with ANSI/SPRI RP-4, *Wind*

Design Standard for Ballasted Single-Ply Roofing Systems (RP-4), and with

- Aggregate-surfaced BUR and sprayed polyurethane foam (SPF) roofs, which the RP-4 standard was not intended to address.

In an attempt to address the roof aggregate blow-off problem, the 2006 IBC implemented severe restrictions on the use of aggregate-surfaced BUR and SPF roofs. These new provisions were not based on the Kind-Wardlaw (K-W) design method (Kind and Wardlaw, 1976), the wind tunnel studies underlying the K-W design method (Kind, 1977), or a quantitative analysis of observed good and bad roofing system performances in real wind events. Consequently, the Asphalt Roofing Manufacturer's Association (ARMA) sponsored research and development of a design methodology to control aggregate blow-off of built-up roofing systems based on the earlier K-W wind tunnel studies and a quantitative comparison to actual field data collected from numerous buildings with aggregate-surfaced roofs experiencing several major hurricane events.

The technical outcome of the ARMA research effort was reported about 10 years ago (Crandell and Fischer, 2010; Crandell and Smith, 2009). Since that time, an additional independent field study has further confirmed the design methodology (Morrison, 2011), and efforts have been aimed at bringing the design methodology into the IBC, which is finally scheduled to occur for the 2021 edition. These new code provisions were the result of research and, to some degree, experience-based judgment and compromise. They will continue to be refined as useful improvements become available with input from research, engineering, and roofing communities. In fact, an effort to further advance the design methodology is in progress between the National Council of Structural Engineers Association (NCSEA) and ARMA, among other interests. This article provides a review to bring readers up to date and provide additional insights.

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DEVELOPMENT AND VERIFICATION OF THE MODIFIED K-W DESIGN METHOD

Research History

As mentioned in the introduction, the primary research on control of roof aggregate scour and blow-off comes from the wind tunnel studies by Kind (1977), which serve as the basis for the K-W design method (Kind and Wardlaw, 1976). Those procedures are the basis of design recommendations in England (BRE, 1986), and they also serve as the basis for the ANSI/SPRI RP-4 standard.

As described in Crandell and Smith (2009), the wind tunnel data were re-evaluated and the K-W design method was revised and simplified to focus just on the initiation of roof aggregate blow-off. The resulting "modified K-W method" focused particularly on the more stringent failure condition of a wind approach quartering a building corner and causing vortices which initiate aggregate blow-off as shown in *Figure 1*.

Additionally, in the same study, the method's ability to predict the occurrence or non-occurrence of roof aggregate blow-off was compared and calibrated to quantitative data from a detailed performance assessment of seven BURs with aggregate surfacing on buildings in three different hurricane events. These were Hurricanes Katrina (RICOWI, 2007), Hugo (McDonald, 1992), and Andrew (Smith, 1997). In 2011, an independent study by Morrison provided additional field verification of the modified K-W design method by comparing predictions with detailed performance observations and data from 19 roofs experiencing hurricane events that impacted Florida in 2004. Morrison's conclusions indicated that the modified K-W design method "appears to be quite conservative."

Measured nominal (median) sizes of roof aggregate in the field verification studies reported by Crandell and Smith (2009) and Morrison (2011) ranged from 0.245 to 1.5 in., with examples shown in *Figure 2*. Roof heights on various building sizes and shapes ranged from 14 to 210 ft. From the field study data, as well as the conservative fit of the modified K-W design method to the original wind tunnel data (Crandell and Smith, 2009), the safety factor implied by the design methodology was found to be about 1.5 in terms of required parapet height (Crandell and Smith, 2009). Morrison (2011) concluded that the design method conservatively under-predicts (on average) the critical wind velocity at blow-off initiation by about 50 mph.

Modified Kind-Wardlaw Design Method

The modified K-W design method is reported as a multi-step design approach in Crandell and Smith (2009), Crandell and Fischer (2010), and Morrison (2011). More recently, the methodology has been condensed to a single equation and aligned

Figure 2 – Samples of aggregate from evaluated roof systems after hurricane events (Morrison, 2011). Photo courtesy of Deer Ridge Consulting Inc.

$$H_p \geq 0.41\ V\ (K_h K_{zt} K_d K_e)^{1/2}\ (d)^{-1/3} - 34.6 \text{ (IP units)}$$

$$H_p \geq 0.068\ V\ (K_h K_{zt} K_d K_e)^{1/2}\ (d)^{-1/3} - 0.88 \text{ (SI units)}$$

where,

H_p = parapet height above loose aggregate roof surfacing, inches (m).
d = nominal aggregate diameter of the specified aggregate mixture, whereby not more than 50% by weight of the aggregate mixture is smaller than d, inches (mm).

Other parameters are as defined in Chapter 26 of ASCE 7 (2016).

Equations 1 and 2

with wind design parameters in ASCE 7 (2016) in order to remain relevant to current model code provisions.

The key design parameters affecting the potential for roof aggregate blow-off include the site's design wind speed and exposure (particularly the wind speed at the roof height), the height of the roof, the height of the parapet, and the size of roof aggregate. Using the earlier modified K-W design method of Crandell and Smith (2009), *Equations 1* and *2* (for IP and SI units) are derived as a means to estimate a minimum parapet height required to control the risk of roof aggregate blow-off.

These equations can be applied to new construction or to evaluate existing construction to assess risk or to consider existing roof performance improvements. However, in its application in the 2021 IBC proposal to develop prescriptive aggregate size and parapet height requirements (discussed elsewhere in this article), some important judgments were made. First, for roof heights over 30 ft. or in areas with basic design wind speed of greater than 110 mph, a minimum parapet height of 12 in. was applied. For buildings of 30 ft. roof height or less and in basic wind speed conditions of 110 mph or less, a 2-in. parapet (essentially a gravel stop) was permitted where the calculated parapet height was less than 12 in. These adjustments were done to align with long-standing accepted practice in low wind regions and, conversely, to provide a minimum parapet height requirement in higher wind regions. In addition, the 2021 IBC table assumes no topographic wind speed-up effects for the building site and is limited to buildings of 150 ft. height or less where the basic wind speed is 150 mph or less. Finally, the above equation should not be used for aggregate nominal sizes that are less than those reported earlier in development and verification of the modified K-W method. A minimum nominal aggregate size of ⅜-in. is used in the 2021 IBC table.

Pre-dating and parallel to ARMA's efforts, SPRI used the same starting point—the Kind-Wardlaw studies—to begin its development of a design standard for ballasted roofing systems. The ANSI/SPRI RP-4 document was first issued in 1997 and has been revised four times since, with the most recent version published in 2019. Similar to the ARMA findings, the supporting research for the SPRI standard results in a document that outlines ballast options, design provisions (to address items such as large openings in walls and rooftop projections), and clearly identified restrictions for configurations that exceed the scope of RP-4. The primary difference between the ARMA table that was approved into the IBC and RP-4 is that the ARMA table is used to determine a parapet height given the set of inputs (wind speed, building height, building exposure, and aggregate size), whereas the tables in RP-4 are separated by a given parapet height; then a building's height and exposure will identify the maximum allowed wind speed for a given stone ballast size.

IBC 2021 CODE DEVELOPMENT

ARMA continued efforts for several code cycles from 2009 to 2021, using existing science as well as additional research as cited above. ARMA's opposition to the code provision is based on opposition to a product ban when control methodology is available. In the fifth code cycle after the 2006 IBC, ARMA was able to get a consensus from the ICC stakeholders. The 2021 IBC is scheduled to contain detailed provisions for the use of aggregate surfacing on low-slope roof systems, and specify appropriate parapet height to reduce the likelihood of aggregate blow-off. Key to the code development effort was a commitment by ARMA to continue work with NCSEA and other stakeholders, including NRCA, IBHS, and SPRI, to improve the provisions in future collaboration.

NEW CONSTRUCTION

Beginning with the 2021 IBC, there will be clear direction on allowable aggregates, provided certain aspects of the building are determined. Those items will be the building's mean roof height, the exposure as determined by ASCE 7-16, and the wind speed for the building's location as determined by ASCE 7-16. Once those three items are known, a designer can then, based on the selected aggregate size, determine the minimum required parapet. *Figure 3* shows the table that will be part of the 2021 IBC.

An examination of the table shows that parapet heights will range from 2 to 56 in. A potential additional benefit of including a parapet for aggregate use is that the parapet could also serve as a guardrail for fall

> The key design parameters affecting the potential for roof aggregate blow-off include the site's design wind speed and exposure (particularly the wind speed at the roof height), the height of the roof, the height of the parapet, and the size of roof aggregate.

TABLE 1504.8
MINIMUM REQUIRED PARAPET HEIGHT (INCHES) FOR AGGREGATE SURFACED ROOFS[a,b,c]

AGGREGATE SIZE	MEAN ROOF HEIGHT (ft)	WIND EXPOSURE AND BASIC DESIGN WIND SPEED (MPH)																	
		Exposure B									Exposure C[d]								
		<=95	100	105	110	115	120	130	140	150	<=95	100	105	110	115	120	130	140	150
ASTM D1863 (No.7 or No.67) or ASTM D7655 (No.4)	15	2	2	2	2	12	12	16	20	24	2	13	15	18	20	23	27	32	37
	20	2	2	2	2	12	14	18	22	26	12	15	17	19	22	24	29	34	39
	30	2	2	2	13	15	17	21	25	30	14	17	19	22	24	27	32	37	42
	50	12	12	14	16	18	21	25	30	35	17	19	22	25	28	30	36	41	47
	100	14	16	19	21	24	27	32	37	42	21	24	26	29	32	35	41	47	53
	150	17	19	22	25	27	30	36	41	46	23	26	29	32	35	38	44	50	56
ASTM D1863 (No.6)	15	2	2	2	2	12	12	12	15	18	2	2	2	13	15	17	22	26	30
	20	2	2	2	2	12	12	13	17	21	2	2	12	15	17	19	23	28	32
	30	2	2	2	2	12	12	16	20	24	2	12	14	17	19	21	26	31	35
	50	12	12	12	12	14	16	20	24	28	12	15	17	19	22	24	29	34	39
	100	12	12	14	16	19	21	26	30	35	16	18	21	24	26	29	34	39	45
	150	12	14	17	19	22	24	29	34	39	18	21	23	26	29	32	37	43	48

For SI: 1 inch = 25.4 mm; 1 foot = 304.8 mm; 1 mile per hour = 0.447 m/s.

a. Interpolation shall be permitted for mean roof height and parapet height.

b. Basic design wind speed, V, and wind exposure shall be determined in accordance with Section 1609.

c. Where the minimum required parapet height is indicated to be 2 inches (51 mm), a gravel stop shall be permitted and shall extend not less than 2 inches (51 mm) from the roof surface and not less than the height of the aggregate.

d. For Exposure D, add 8 inches (203 mm) to the parapet height required for Exposure C and the parapet height shall not be less than 12 inches (305 mm).

Figure 3 – This is the table that will be part of the 2021 IBC.

protection. With the serious nature of fall protection systems, it must be clear that if a parapet is meant to serve in this role, it must comply with all building code provisions, as well as applicable state, local, and OSHA fall protection requirements. OSHA requires that guardrails be 42 in., plus or minus 3 in. above the walking-working surface. A guardrail can exceed 45 in., provided that all other criteria for a guardrail is met per OSHA Part 1910.29(b). Should the parapet be sufficient to serve as a fall protection system, a proper evaluation of its costs should not be restricted to its role as part of the roofing system.

Where a gravel stop is being considered (per footnote c in *Figure 3*), the 2-in. height required is from the roof surface, but it must be higher if the depth of the aggregate exceeds 2 in. A key consideration with a gravel stop is that its design should be evaluated for its performance in relation to wind loads. As can be seen with the example tested design in *Figure 4* (from NRCA's website), while the geometry of this could meet the height requirement in the new table, its performance is based on the exact geometry and materials used. Any time a gravel stop is being utilized with this provision, care must be taken to ensure that the gravel stop meets the other requirements outlined in the code for edge metal performance. It should be noted also that ASCE 7 contains provisions for determining wind loads that parapets must resist.

EXISTING BUILDINGS AND REROOFING

While many consider aggregate surfacing installed on roof systems as either low-maintenance or even no-maintenance options, it must be acknowledged that the aggregate is serving a purpose in protecting the roofing system installed beneath. As such, the maintenance of this surfacing is just as vital to the successful life cycle realization as any other component or installation process of the roofing system. Since it is a surfacing, removal and replacement of the surfacing should be considered as maintenance under the *International Existing Building Code (IEBC)*, per the definition of "roof repair," which states:

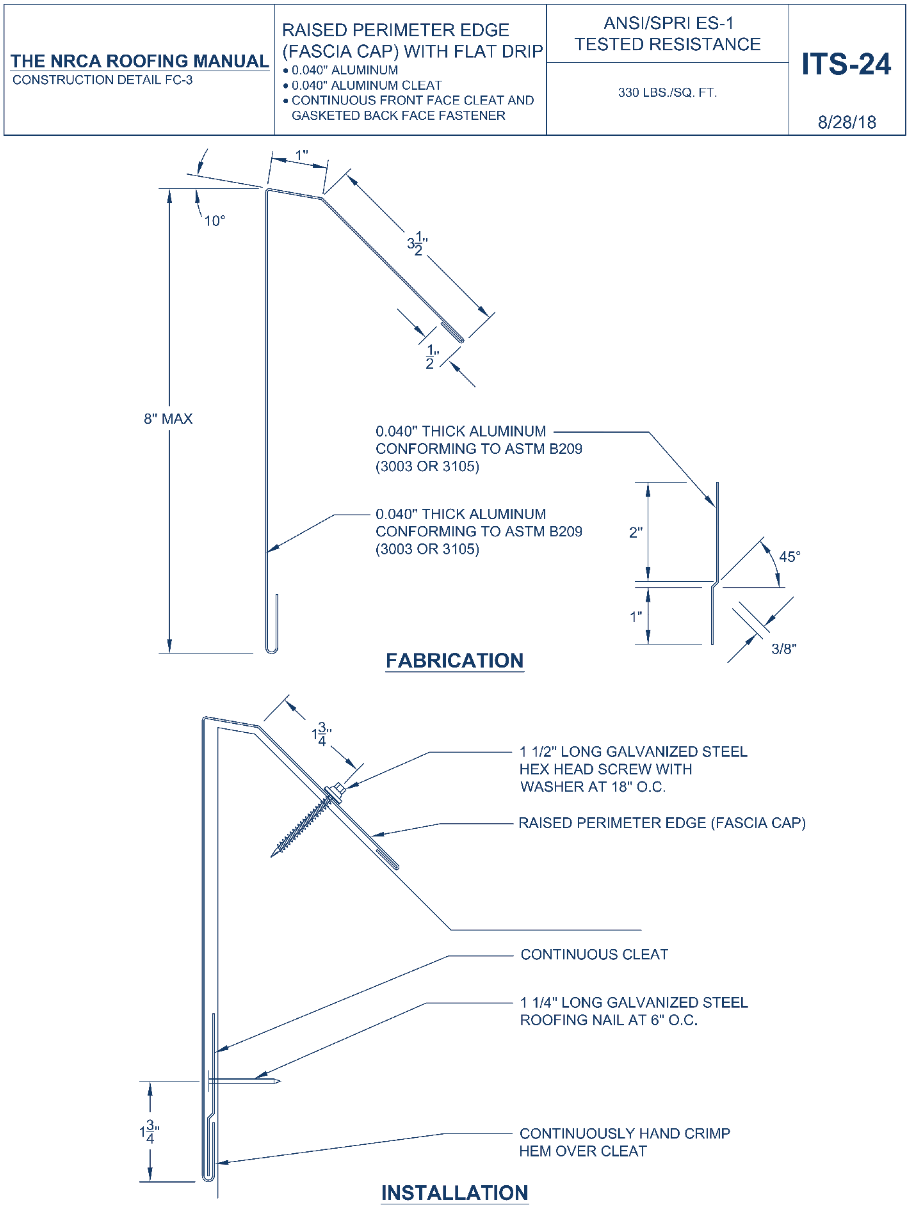

Figure 4 – Example tested design from NRCA's website.

> ROOF REPAIR – The reconstruction or renewal of any part of an existing roof for the purpose of correcting damage or restoring the predamage condition.

Further, when considering the IEBC, "reroofing" is defined as a level 1 alteration. However, the "repairs" section (addressed in Chapter 4) states that work shall not make the building less compliant than it was before the repair was undertaken. Replacement of the surfacing could be considered maintenance of the roofing system and, thus, allowed.

As roof designers evaluate reroofing projects on existing buildings with aggregate surfacing, consideration should be given to identifying opportunities to improve the overall performance of the system. Using parapets to serve two purposes—fall protection and limiting aggregate blow-off—should be one of those considerations. Selecting a larger permitted aggregate size also is an option in combination with an appropriate parapet height.

Additionally, the 2017 Florida Building Code (FBC) includes provisions for the use of aggregate surfacing:

> **1504.8 Aggregate.**
> Aggregate shall be permitted as roof surfacing when installed on slopes of 3:12 or less; not less than 400 pounds (182 kg) of roofing gravel or 300 pounds (145 kg) of slag per square shall be applied. A minimum of 50 percent of the total aggregate shall be embedded in the flood coat of bitumen or installed in accordance with its product approval. Aggregate shall be dry and free from dirt and shall be in compliance with the sizing requirements set forth in ASTM D1863. A building official may request a test to confirm compliance with these requirements.

This provision for embedment of the aggregate into the asphalt flood coat is intended to reduce the chance of scour and blow-off from high winds. It should be noted that the FBC does not contain parapet height provisions. Using this prescriptive method for reroofing projects where the addition of a parapet is not possible due to budget or other concerns could offer an enhanced option that is also code-compliant in Florida.

Where the use of a designed parapet for reroofing projects is possible, it should be noted that a parapet may provide additional benefits beyond aggregate blow-off and fall protection by reducing the wind uplift pressures on the roof assembly. This is especially important to consider when evaluating existing buildings for structural retrofit triggers in the IEBC. ARMA recommends that the roof designer evaluate all of the variables to determine the best approach for any project.

FUTURE RESEARCH

While the modified K-W method has been proven to be simple and effective, it could benefit from additional research. Based on input from the code development process and other sources of experience, some potential research interests or needs are as follows:

- Better quantification of the "safety factor" associated with the modified K-W design method through additional field studies with sufficient data collection to allow comparison to design predictions
- Refinements to allow reduced parapet heights at an adequate distance from corners of the building (and confirm adjustments for this pur-

pose in Kind and Wardlaw [1976])

- Conduct controlled, full-scale wind tunnel tests to:
  - Confirm the aggregate size adjustment factor used in the design methodology for a range of aggregate sizes and parapet height conditions
  - Evaluate impact of sustained scour in long-duration wind events to determine any potential influence of aggregate redistribution and "pile-up" on downwind parapets regarding blow-off potential
  - Determine the significance of rooftop equipment, penthouses, and other roof features that may create localized vortices or cause roof surface wind speed-up, away from roof corners
  - Evaluate any potential effect of roof membrane flutter or "pumping" for mechanically attached single-ply roof membranes
  - Confirm that use of nominal aggregate diameter as a basis for aggregate size in the design method adequately addresses the smaller aggregate sizes in the aggregate size distribution (as further confirmation of the scaled wind tunnel studies and field verification study findings)

It should be noted that many of the above research interests have been captured to some degree in the already-completed field verifications of the design methodology (Crandell and Smith, 2009; Morrison, 2011). However, better-controlled laboratory experiments would allow a more thorough evaluation and confirmation. From a practical perspective, research on low-cost means to add parapets to existing building roof perimeters should be the subject of investigation and demonstration as a mitigation solution when needed.

SUMMARY

The 2021 IBC requirements for parapet design related to aggregate surfacing represent a new opportunity for aggregate-surfaced roofs. While future research and code development will likely add guidance for designers, the basic wind science has been well established. Using a parapet to raise the wind field and limit exposure of the roof surface is the foundation of the new requirements. There is a need to educate designers and roofing contractors on the code requirements and to communicate to building owners, architects, and other interested parties on how the new code requirements work.

Aggregate-surfaced BURs provide many desirable features for buildings in high-wind areas. With the improvements contained in the 2021 IBC, designers and contractors will have greater guidance on how to use aggregate-surfaced roofing systems and reduce the chance of blow-off. As the industry develops additional guidance on the design issues, the use of this time-proven, durable, and sustainable roofing system can grow.

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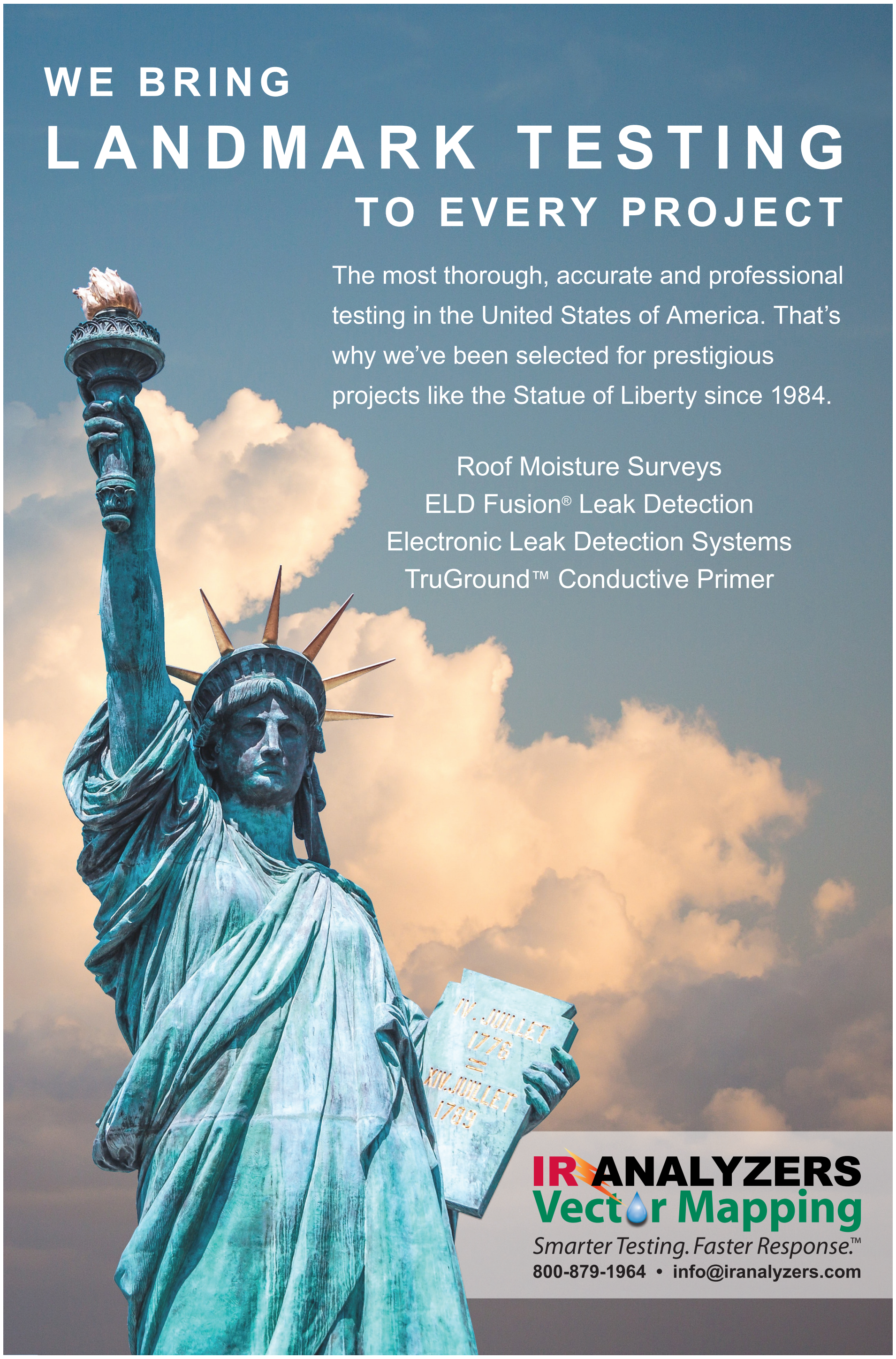

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Jay Crandell, with ARES Consulting, has over 30 years of experience in construction, engineering, and innovative building technology research for private- and public-sector clients. He has conducted benchmark studies of major natural disasters and research to address significant structural, energy, and building science challenges. His work has helped to propel many innovative technologies into the international codes and consensus standards. He is widely published on various engineering, construction, and building science topics.

Chadwick Collins

Chadwick Collins, technical director for ARMA, has spent his entire career in the technical side of the roofing industry, including field technical services, product and system testing, and code and standard development. Before joining the ARMA team, he worked for two manufacturers and an engineering consulting firm. Chadwick holds a BS in mechanical engineering, was previously certified as a Registered Roof Observer, and is currently a licensed drone pilot and member of ASTM, ICC, and IIBEC.

Duro-Last Retools to Manufacture PPE

Duro-Last Inc., Saginaw, MI, quickly retooled after the outbreak of the COVID-19 virus to manufacture medical personal protective equipment (PPE). Employees in engineering, sales, manufacturing, and research and development got together on March 20 and were manufacturing gown and mask designs a week later, they report.

The company manufactures flexible thermoplastic roofing membranes, so retooling some of their equipment to manufacture medical isolation gowns and face masks of polyester and flexible, transparent PVC was not a huge stretch.